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ABSTRACT

This 1-week study explored the extent to which high school students (n=140) acquired meaningful understanding of selected biological topics (meiosis and the Punnett square method) and the relationship between these topics. This study: (1) examined "mental modeling" as a technique for measuring students' meaningful understanding of the topics; (2) measured students' predisposed; generalized tendency to learn meaningfully; (3) determined the extent to which students' meaningful learning orientation predicted understanding beyond that predicted by aptitude and achievement motivation; (4) examined the consistency of the level of meaningful understanding acquired across the different biology topics; (5) experimentally tested two auto-tutorial instructional treatments (relationships presented to students, relationships generated by students); and (6) explored the influence of meaningful learning orientation, prior knowledge, instructional treatment, and all interactions of these variables in predicting meaningful understanding. The results of correlations and multiple regressions indicated that meaningful learning orientation generally contributed to students' attainment of meaningful understanding independent of aptitude and achievement motivation. Students attained similar levels of meaningful understanding across the different topics and on the relations between the topics. (Author/PR)

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Students' meaningful learning orientation and their meaningful understandings of meiosis and genetics.

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ABSTRACT

This study explored factors predicting the extent to which high school students (N = 140) acquired meaningful understanding of selected biological topics (meiosis and the Punnett square method) and the relationship between these topics. This study: (1) examined "mental modeling" as a technique for measuring students' meaningful understanding of the topics, (2) measured students' predisposed, generalized tendency to learn meaningfully (meaningful learning orientation), (3) determined the extent to which students' meaningful learning orientation predicted meaningful understanding beyond that predicted by aptitude and achievement motivation, (4) examined the consistency of the level of meaningful understanding acquired across the different biology topics, (5) experimentally tested two auto-tutorial instructional treatments (relationships presented to students, relationships generated by students), (6) explored the influence of meaningful learning orientation, prior knowledge, instructional treatment, and all interactions of these variables in predicting meaningful understanding. The results of correlations and multiple regressions indicated that meaningful learning orientation generally contributed to students' attainment of meaningful understanding independent of aptitude and achievement motivation. Students attained similar levels of meaningful understanding across the different topics, and on the relations between the topics. Additionally, meaningful learning orientation and prior knowledge interacted in unique ways for each topic to predict students' attainment of meaningful understanding. Instructional treatment had relatively little influence on students' acquisition of meaningful understanding. The primary and consistent finding was that students' meaningful learning orientation was a significant factor of their meaningful understanding of the topics and of the relations between the topics. These findings imply that meaningful learning orientation may influence the level of understanding students attain and should be given considerable attention in science teaching. Educators should work toward helping students learn to formulate relations between new information and relevant prior knowledge so they may acquire more inter-related, meaningful understandings of science.

Students' meaningful learning orientation and their meaningful understandings of meiosis and genetics.

Introduction

When asked to describe the relationship between meiosis and the use of Punnett square method a high school biology student explained the following:

Subject ID # 121

I don't think there could logically be a relationship; the Punnett square demonstrates fertilization, not meiosis.

In this explanation, the student correctly expressed what the Punnett square method illustrates (union of gametes), but apparently could not envision how meiosis (preparation of gametes) relates with its use in solving genetics problems. This students' response may or may not be representative of all students. Nonetheless, it raises some important questions as to whether students in general are formulating important relations between ideas and concepts when learning science.

A primary goal of science education is that students do formulate sound conceptual knowledge about the world and how it works. Students should acquire knowledge, not by memorizing isolated facts, but through the formulation of relationships among ideas. The inter-related understandings that students acquire should further allow them to create new ideas from what is already known.

The formulation of non-arbitrary relationships between ideas in the learner's mind was described by Ausubel (1963, p.23) as "meaningful learning." Meaningful learning is a constructive process in which the learner strives to formulate links among existing conceptions, information and observations of science to accomplish understanding (Novak, 1988; Pines & West, 1986). New concepts are subsumed by existing conceptual structures in meaningful learning and in the process, the learner must construct links between old and new ideas. Informational links constructed in meaningful learning results in a structured body of scientific knowledge (Pines & West, 1986).

Many students however, tend not to learn meaningfully and thus may have difficulty relating what is taught to them in science with other science ideas, as well as with their real-world experiences (Novak, 1988). Instead, much of their learning tends to involve memorization of facts in which newly learned material is not

related in ways that make sense to the learner (Novak, 1988). In rote learning, new knowledge is thought to be attained by verbatim memorization and incorporated into a person's knowledge structure without connecting it to information or frameworks previously acquired (Novak, 1988). Concepts learned by rote are not "subsumed" and do not fit within one's conceptual structure in any sensible way. Thus, a conceptual framework of understanding is not developed and therefore does not serve as the basis for new understanding.

Students' meaningful learning of meiosis and genetics are of special concern to science educators since these topics are often learned by rote (Browning, 1988; Cho, Kahle & Nordland, 1985; Stewart, 1982: Stewart & Dale, 1989). Students tend to learn these topics in isolation with one another and may not formulate conceptions of how these topics are related (Cho, Kahle, & Nordland, 1985; Stewart, 1982). This may be illustrated by students' successful use of Punnett square diagrams in genetics without attaining an understanding of the concepts represented by their use, and without formulating a conceptual link with the segregation of alleles in meiosis and the recombination of such in fertilization (Browning, 1988; Stewart, 1982).

A study of high school students by Stewart and Dale (1989) revealed that after meiosis and genetics instruction, most students were able to correctly solve Punnett square diagrams, but did so with little or no understanding of chromosome/gene behavior during meiosis (Stewart & Dale, 1989). Several students tended to use the Punnett square diagram as an algorithm to correctly solve genetics problems. Using the Punnett square diagrams in this manner however, leaves students virtually unable to connect probabilities derived from this method with the processes of meiosis and the distribution of genetic traits (Cho, Kahle, & Nordland, 1985; Kinnear, 1983).

Although many students in Stewart and Dale's (1989) study correctly reproduced information of meiosis and the Punnett square method without relating these topics, there were some students who did make connections (Stewart & Dale, 1989). Why do some students apparently attain only rote understandings of these biological topics whereas others attain more conceptually inter-related, meaningful understandings? It may be argued that students who attain meaningful understandings of topics studied are simply those students with greater academic ability. It may also be argued that students attaining meaningful understandings have a greater motivation to achieve in their academic work (Entwistle & Ramsden, 1983). While academic ability and motivation may play a role in the acquisition of meaningful understanding, other factors may be at work.

It is proposed in this study that, in addition to ability, motivation and other factors, there is a distinct variable which contributes to students' meaningful understanding of subject matter. That variable, called "meaningful learning orientation," is the extent to which students approach a learning task with the intention of meaningfully understanding the ideas and relationships involved (Donn, 1989; Entwistle & Ramsden, 1983; Entwistle & Waterston, 1988).

Meaningful learning orientation

Student's meaningful learning orientation may be an extension of one of the criteria of meaningful learning (meaningful learning set) first put forth by Ausubel (1963,1968). According to Ausubel (1963, 1968), for meaningful learning to take place: (1) The learner must be provided with meaningful learning tasks. This criteria requires that the material to be learned has the potential to be connected within the person's knowledge structure in a meaningful way. (2) Relevant prior knowledge must be possessed by the learner, that is, the learner needs to have a conceptual framework with which to link the new concepts to be learned. (3) The learner must "manifest" the **meaningful learning set**. To fulfill this criteria, the learner must actively attempt to relate substantive aspects of **new concepts, information** or situations to construct understanding (Ausubel, 1963, 1968; Novak, 1988). This final **criteria for meaningful** learning necessitates that individuals choose to connect new knowledge to pertinent concepts and propositions of their existing knowledge (Novak, 1988).

Although relevant prior knowledge and meaningful learning tasks are important variables and are also explored in this study, the criteria of "meaningful learning set" (meaningful learning orientation) is the central focus. Meaningful learning set implies that learners must have the desire or tendency to make connections among concepts, and recent literature indicates that this is important regardless of how they acquire new concepts (Osborne & Wittrock, 1983, 1985). According to Osborne and Wittrock (1983), "even when a teacher gives a pupil an explanation for how and why something behaves as it does, the pupil must still actively create meaning from that explanation," (p.205). Essentially, learners cannot construct knowledge when listening to a lecture, reading a text or engaging in other instructional activities without exerting intellectual effort (Osborne & Wittrock, 1985; Wittrock & Lumsdaine, 1977). To learn meaningfully, students need to take responsibility for their own learning by actively formulating links and constructing sensible understandings.

It is reasonable to believe that some students do choose to make meaningful connections when presented with information, and some may make more connections and more appropriate connections than other students. Still other students do not choose to make connections (or possibly do not know how to make them) and learn by memorizing facts in isolation from other ideas (Donn, 1989; Edmonson, 1989; Robertson, 1984). Is the level in which students "manifest the meaningful learning set," or the extent to which they tend to relate concepts with each other and with observations, a general and identifiable factor of student learning?

Research suggests that students may indeed have a predisposed learning orientation; for some students it is meaningful learning for other students it is rote learning; and that this orientation can be identified (Atkin, 1977; Donn, 1989; Edmonson, 1989; Entwistle & Ramsden, 1983; Robertson, 1984). In research in a college organic chemistry course, Atkin (1977) identified students as knowledge "integrators" and "non-integrators" with respect to the way they learn. Edmonson (1989) identified cases of students she categorized according to their philosophical views of science and after interviews, identified students as rote learners, meaningful learners and those mid-range between the two learning approaches. In a study which involved observations and video-taped stimulated recall interviews of college biology students in the laboratory, Robertson (1984) concluded that some students tended to use rote strategies in learning and others tended to formulate relationships, or learn meaningfully.

The proposition that students vary in their meaningful learning orientation (meaningful, rote) was also addressed in a study by Donn (1989). Donn (1989) used a Likert-type instrument, adapted from the work of Entwistle and Ramsden (1983), to identify meaningful and rote learners and subsequently found a clear distinction in their approach to learning new concepts. Meaningful learners responded to novel problems by self-questioning, and by relating and elaborating ideas. In contrast, rote learners responded by stating definitions and could not extrapolate their ideas (Donn, 1989).

Based on the research cited above, the possibility is raised that students tend to use different strategies or approaches when they learn science. Some students tend to meaningfully learn, others apparently learn by rote, and still others may learn between meaningful and rote. Additionally, students' meaningful or rote (or mid-range) learning approaches can be identified using inventories such as that developed by Entwistle and Ramsden (1983) and modified by Donn (1989), and/or by observations as was

done in Robertson's (1984) study. Since each of these techniques separately provides an identification of students' meaningful learning orientation, then a combination of self-reports and observations of students' learning should provide a more complete and "potent" measure of students' learning orientations. If students view themselves as either rote or meaningful learners (or in between), and observations verify their learning approach, the likelihood of an accurate identification of their learning orientation (meaningful, rote) is enhanced. The next important task is to identify method(s) for measuring the students' attainment of meaningful understanding.

Measuring the attainment of meaningful understanding

It can generally be said that meaningful learners would likely formulate quite complex understandings of meiosis, the Punnett square method and the relationship between these topics compared with those who learn the same information by rote. Possible differences in meaningful and rote learners' understandings however, may not be detected using traditional testing procedures, since many students are able to obtain correct answers on tests with only rote-level knowledge of the subject matter (Ridley & Novak, 1983). Rather than assessing students' responses to a specific and possibly teacher-biased set of questions, an open-ended response mechanism would be useful in order to better reveal the extent and nature of students understandings. An assessment technique, called "mental modeling" (Kirsch & Mosenthal, in press; Mosenthal & Kirsch, 1991; Mosenthal & Kirsch, in press), fulfills this criteria in that it provides a detailed depiction of students' understandings of relations between concepts and ideas they have studied. These understandings can further be determined as ranging from rote-level to meaningful-level understanding (Cavallo, 1991).

The mental model technique requires that students provide a comprehensive written description of their understanding of a particular topic. The knowledge that students express is parsed into individual, information-bearing propositions, which are then mapped on a template or grid. The template is used to categorize conceptual and process (or procedural) knowledge in students' descriptions and represents levels (meaningful, mid-range, rote) of understanding. Students with a meaningful understanding of the topic use a broad range of both conceptual and process (or procedural) knowledge categories to describe a topic. In conceptually describing meiosis, for example, these students can describe objects (such as cells) and actions involved

(such as division) and can integrate this knowledge with locations where the process occurs (i.e., in the body, in the gonads), directions of movement (i.e., toward the center of the cell), conditions or constraints (i.e., only in specialized cells). and can even extrapolate on the process with a description of how certain agents (such as, the influence of drugs) can cause certain effects (such as, damage to chromosomes, and problems in the gamete and fertilized egg). In addition, students with a meaningful understanding show knowledge of the how the process works. In meiosis, they would have indicated knowledge that two cell divisions occur (major processes) and that activities occur in the cell within the stages of meiosis, such as chromosomes duplication (minor processes).

Students who describe the topic using only one or two knowledge categories have a rote knowledge of the topic. These students would typically explain only objects and actions involved in meiosis. Students may describe, for example, actions such as replication, and objects such as cells and chromosomes, but they do not integrate this knowledge with where meiosis occurs in the body (or that it even occurs in a body), how the process occurs, what conditions are necessary for it to occur, what the results of the process are (gametes), and what situations might cause certain effects. In essence, their propositions about chromosomes and cells are explained in isolation with other information which indicates recall of facts rather than an inter-related conceptual understanding of the process. The final result of the mental model procedure is a qualitative description and quantitative measure of learners' meaningful or rote understandings on any given topic.

Important to this study is that, using mental modeling, students' learning orientation (meaningful, rote) could be explored in terms of whether or not it coincides with the understandings (meaningful, rote) they illustrate in their descriptions. This form of assessment could also reveal whether students consistently attain rote knowledge of the different topics, or meaningful understandings, or if there is no pattern to the levels of understanding they attain. Finally, along with learning orientation, Ausubel's (1963) other criteria for meaningful learning (prior knowledge and meaningful learning tasks) can be explored with respect to the meaningful understandings they attain (as measured by mental models).

Prior knowledge and meaningful understanding

Of the three criteria for meaningful learning mentioned, relevant prior knowledge possessed by the learner has been described by Ausubel (1963, 1968) and Novak (1988) as very important for meaningful learning. If students' learning orientation, ranging from meaningful learning to rote, is a factor in their attainment of meaningful understanding (meaningful mental model), then what is the role of relevant prior knowledge of the topic to be learned? Are students who learn meaningfully those with greater relevant prior knowledge of the topic to be learned?

Although students' prior knowledge is likely an important factor in their attainment of meaningful understanding (Novak, 1988), some students may still tend not to connect new ideas to that prior knowledge. Therefore, attaining a meaningful understanding may not only require relevant prior knowledge, but also an orientation toward meaningfully learning the material. Does this mean that students with little or no prior knowledge of the topics they are studying do not attain a meaningful understanding of the material? Perhaps, if the material presented has the potential to be meaningfully learned (Ausubel, 1963, 1968), students with a meaningful learning orientation can attain meaningful understanding even with little or no prior knowledge of the topics studied. Yet more importantly, if prior knowledge is possessed by the learner, a meaningful learning orientation may add significantly, or interact with the attainment of meaningful understanding of instructed material.

Instruction and meaningful understanding

Another of Ausubel's (1963) criteria contends that meaningful learning tasks should be provided for students in instruction in order for them to attain meaningful understanding of topics to be learned (Ausubel, 1963, p.18). Ausubel (1963, p.19) claims that, for older students, "reception learning" is an effective and efficient way for students to attain meaningful understandings of the material. In reception learning, students can acquire meaningful understandings by being taught in an expository manner in which the information and relationships are described for them. In contrast, Osborne and Wittrock (1983) and Wittrock and Alesandrini (1990) pose that students must actively "construct" relationships themselves to formulate meaningful understanding. Of interest in this study is, as long as meaningful learning tasks are provided, whether students

acquire greater meaning from instruction which presents relations (reception learning) or from instruction which requires students to construct or generate relationships themselves (generative learning). Of greater interest, however, is how the method of instruction (reception versus generative) differentially influences those students with a meaningful learning orientation and those students with a more rote learning orientation. For example, do meaningful learners attain a meaningful understanding regardless of whether they are told relationships or construct relationships themselves? Do students tending to learn by rote formulate meaningful understandings when told the relationships, but not when asked to construct relationships themselves? This study attempts to provide preliminary answers to the questions posed in this introduction. Specifically, the purposes of this study were to:

1. Determine whether or not students' learning orientation (meaningful, rote) is a variable that is distinct from other variables (academic ability and achievement motivation) which tend to influence acquisition of meaningful understanding.

2. Examine the extent to which learning orientation relates with the attainment of meaningful understanding across different but related biological topics (meiosis and the Punnett square method) and, in doing so, acquire some information regarding the extent to which learning orientation is a more general or specific characteristic of student learning.

3. Evaluate the relative importance of relevant prior knowledge, learning orientation and instructional approach (reception, generative) in determining the acquisition of understanding.

4. Explore all possible interactions between meaningful learning orientation, relevant prior knowledge and instructional approach as predictors of students' attainment of meaningful understanding of meiosis, the use of the Punnett square method in genetics and the relations between these two topics.

Methodology

Sample

The sample consisted of 163 tenth grade students (average age 15.5 years) attending a suburban high school in Central New York State. The students were enrolled in Regents Biology (a college preparatory course) in seven classes taught by four different teachers. Due to absenteeism, 140 students (70 males and 70 females) were used in the analyses for this study. The ethnic background of the sample was 139 caucasian, and 1 Asian-American.

Procedures

The study involved six major procedures:

1. Meaningful and rote learning orientations of students were identified using a composite score from the Learning Approach Questionnaire (LAQ) and teacher ratings of their students' learning approach.
2. Student aptitude test scores were acquired from the Differential Aptitude Test (DAT).
3. An achievement motivation questionnaire was administered to students.
4. A mental model test was administered to assess students' prior knowledge of meiosis. [1]
5. After instruction on meiosis by students' classroom teachers, one of two type-written, auto-tutorial instructional treatments were administered to students.

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[1] Mental model pre-tests were also administered on the Punnett square method, and on the relationship between meiosis and the Punnett square method. It was found that students had essentially no knowledge of these topics.

6. Mental model tests were used to assess students' meaningful understanding of meiosis, the Punnett square method and the relationship between meiosis and the Punnett square method.

To control for possible differential influence in students' writing skills, written expression ability scores were obtained from Tests of Achievement and Proficiency (TAP Manual, 1986), which has a reported Cronbach alpha reliability score as r = .88. Written expression ability factored into the analyses did not influence the results of this study in any way.

Time Frame

The study was conducted at the time the genetics unit is normally taught at this school. All teachers customarily gear their instruction according to a departmentally-designed syllabus and students at this school are regularly given printed instructional packets that coincide with each unit of the course. Thus, the administration of pre-written instructional packets in this study was not novel for students. In addition, the teachers use the same instructional materials and present each unit at the same time during the academic year, so all students had similar background information of the course before beginning this study. The implementation of questionnaires, tests and instruction took place over a period of approximately one week.

Instruments

Learning Approach Questionnaire. The Learning Approach Questionnaire (LAQ) is a 50-item Likert instrument for measuring students' tendency to learn meaningfully or by rote and students' epistemological view of science (Biggs & Collis, 1982; Donn, 1989; Edmonson, 1989; Entwistle, 1981; Entwistle & Ramsden, 1983; Novak, Kerr, Donn, & Cobern, 1989). This study used only those questions (24 total) that addressed students' meaningful or rote approach to learning. The instrument asked that students respond to questions regarding how they learn, ranging from A (always true) to E (never true). A Cronbach alpha internal consistency coefficient for this instrument was reported as 0.77 (BouJaoude, in press). The Cronbach alpha internal consistency coefficient for the 24 questions used in this study was determined as, r = .54. Sample questions from the LAQ include the following:

	Never True				Always True
7. I go over important topics until I understand them completely.	A	B	C	D	E
12. I learn some things by rote, going over and over them until I know them by heart.	A	B	C	D	E

A response of "always true" on question 7 above would indicate a strong tendency toward meaningful learning, while a response of "always true" on question 12 would indicate a strong tendency toward rote learning. After taking the LAQ, students' scores were listed in order and divided into four categories as shown in Figure 1.

Insert Figure 1 About Here

Teacher ratings. The four teachers in this study rated their students according to their perception of each student's general approach to learning: meaningful, rote, or in between meaningful and rote. The teachers were prepared to make their ratings after participating in three training sessions led by the researcher (see Cavallo, 1991), which took place during two months before administration of the treatments. The teachers rated their students according to a four-category ranking: 4 = More meaningful learners, 3 = Less meaningful learners, 2 = Less rote learners, 1 = More rote learners.

Composite meaningful learning orientation rating. The students' self-ratings and teachers' observation-based ratings were analyzed for "matches" and "mis-matches". Of the 140 students in the sample, 94 students had ratings that matched their teachers' rating. Since both ratings agreed, these 94 ratings were considered more representative of the students' learning approach and thus, these students were used in the major analyses of this study. The remaining 46 students' data were analyzed separately and results of those analyses are reported elsewhere (Cavallo, 1991).

Differential Aptitude Test. Student aptitude was determined using the Differential Aptitude Test (DAT) scores obtained from the school guidance counselor. The DAT is an examination used to provide information

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about students' abilities in a variety of areas of mental activity (Bennett, Seashore, & Wessman, 1989). Reliability scores using the Spearman-Brown ranged from r = .88 to r = .94.

Achievement motivation. Achievement motivation was defined in this study as the motivation for students to achieve high grades. The questionnaire used for measuring achievement motivation was a 30-item subscale of a 65-item Likert instrument designed and used by Dweck (1986) and by Ames and Archer (1988). This subscale measured students' orientation toward performance, or a desire to "attain favorable judgments (i.e., high grades) of their work" (Dweck, 1986, Ames & Archer, 1988). The Cronbach alpha reliability coefficient for the 30-item subscale was determined as, r = .89. Examples of items on the achievement motivation questionnaire are shown below.

6. In this biology class, how satisfied do you feel when you...

	a little				a lot
b. get a good grade	1	2	3	4	5
d. do better than other students in the class	1	2	3	4	5

11. Think back over all the science classes you have had in school. In general, when did you feel most successful?

	strongly disagree				strongly agree
c. When I scored higher than other students	1	2	3	4	5
f. When I showed people I was smart	1	2	3	4	5

A high score on the questionnaire represented a high performance oriented individual--one who desires favorable judgments in terms of high grades, or teacher, peer and parental approval.

Pre-test mental models. The students were given a mental model pre-test to assess their prior knowledge of meiosis. In this test, students were asked to write everything they knew about meiosis. Students

were also informed that spelling and grammar would not be counted against their grade. They were also told that they were to write as much as they could and that diagrams could be used with their explanations.

Instruction. Type-written, auto-tutorial instructional packets were used in this study in an effort to control for differential teacher influence. The instructional packets were largely based on the computerized auto-tutorial instruction developed by Browning (1988) which, like Browning's instruction, incorporated the methods for meaningful instruction suggested by Cho, Kahle and Nordland (1985), Stewart (1982) and Tolman (1982). The instruction was entitled, "Genetics: The Inheritance of Traits." Topics in the instructional packets included, "Chromosomes," "Meiosis," "Fertilization," "Genetics," and "The Inheritance of Traits." In the section entitled, "The Inheritance of Traits," the use of the Punnett square method was introduced, and the relationship between meiosis and the use of the Punnett square method in genetics was discussed.

At the closing of each topic within the packet, students encountered a set of multiple-choice and short answer questions, modelled after Browning's (1988) instruction. At that point, students were to answer the questions, then check their responses with colored answer sheets placed in specific areas in the classroom. An important modification made to Browning's (1988) instruction involved the use of an additional set of questions written by the researcher and reviewed by a panel of science education experts. These questions appeared in the final instructional section which related meiosis and the Punnett square method. The questions were designed to help students make cognitive links between meiosis and the Punnett square method and enable them to formulate relationships between the two topics.

The instructional packets were pilot tested using 21 high school Regents Biology students from another area suburban school. The instructional packets were critically analyzed for validity of content and pedagogy by two university biologists, three science education professors and two high school biology teachers. The critical analyses of the students and the reviewers were used to modify the instructional packets and produce the final forms.

Instructional treatments. Two variations of the auto-tutorial instructional packets were randomly assigned to the subjects in this study. One treatment was based on the model of reception learning (Ausubel, 1963) and the other on generative learning (Osborne & Wittrock, 1983). In both treatments, the presentation of meiosis, fertilization, the inheritance of traits and the Punnett square method were identical, as well as all

examples, diagrams and questions used to monitor learning at the end of each section. The variation occurred in the section stressing the relationship between meiosis and the Punnett square method.

In Treatment 1 (reception treatment), the portion of instruction specifically relating meiosis with the Punnett square method included questions, highlighted in boldface print. These questions specifically addressed the relationship between meiosis and the Punnett square method, and in this treatment, answers to the questions were provided. Thus, the information needed for students to formulate conceptual links between these two topics was told to the students.

In Treatment 2 (generative treatment), the portion of instruction relating meiosis with the Punnett square method included the same questions as in Treatment 1, highlighted in boldface print. These questions specifically addressed the relations between meiosis and the Punnett square method but students were to construct the answers to the questions themselves. The questions were provided, but blank spaces appeared beneath each question for students to fill in their own conceptualizations of the relationship. The responses to these questions were not graded and students were not given direct feedback. They did answer a set of multiple-choice and short answer questions after completing the section on the relationship and corrected their answers to these responses (the same as in Treatment 1). The intention of not providing answers to students for the relations questions within the instruction was to find if and how students formulated the relationships themselves, as determined by the post-instruction mental model test.

With the exception of the answers to relational questions the treatments were identical and had about the same number of pages. Since students worked individually, the differences between the packets, and hence, the treatments were not readily detectable by the students. These precautions were taken to minimize a Hawthorne effect of the treatments. Fidelity of the treatment was maintained by having students work on their own. The individual nature of the work was emphasized and reinforced by the teachers and researcher throughout the study.

Post-test mental models. After administration of the instructional packets, students were given a three-question mental model test on meiosis, the Punnett square method and the relationship between these topics. Students had been informed that their work on the post-test would count toward their course grade in order to ensure students were exerting their best effort in their writing. Once again, students were informed that

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grammar and spelling would not count against their grade, and that they could use diagrams to help with their explanations.

Data Analyses

The data used in assessing meaningful understanding were acquired from students' written explanations of meiosis, the Punnett square method, and the relationship between meiosis and the Punnett square method (mental model assessment) before and after the instructional treatments. The method of assigning scores for these mental model tests first involved transcribing students' expositions. Written statements were separated, or "parsed" into propositions, which were mapped on templates with columns. The propositions were written in these columns under headings representing conceptual knowledge (actions, objects, agents, effects, results, reference points, directions, conditions), and either process knowledge for meiosis (major processes, minor process) or procedural knowledge for the Punnett square method (major procedures, minor processes).[2] For mental model explanations of meiosis and Punnett squares, students' conceptual and process (or procedural) knowledge was scored, and the scores were plotted on a matrix (see example, Figure 2). For the mental model explanations of the relationship between meiosis and the Punnett square method, students process knowledge of meiosis *as related* with procedural knowledge of Punnett squares was scored and plotted on a matrix. These scores represent their "meiosis and Punnett square method combination" scores. Since students could write complex conceptual explanations of one topic without ever mentioning the other topic, their conceptual understanding of the relationship was scored differently (technique to be discussed shortly).

Insert Figure 2 About Here

Scores on meiosis, the Punnett square method, and their meiosis and Punnett square method combination ranged from 0 to 3. These scores were used in the data analyses.

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[2] A detailed description of the method for scoring students' mental models is documented in Cavallo, 1991.

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A second scoring procedure (in addition to the mental model procedure) was administered to students' written explanations of the third test question, the relationship between meiosis and Punnett square method. The procedure involved an analysis of the statements students made within their essays that specifically linked meiosis and the use of the Punnett squares method. Statements which related meiosis and the Punnett square method were scored according to accuracy, and according to the amount of detail about the relationship that students described in their essays. Figure 3 shows the statements made about meiosis and the statements made about Punnett squares which, as determined by students' essays, were found to accompany them. Any of the statements made by students in their explanations about meiosis were found to be completed by any of the statements made about Punnett squares shown in Figure 3.

Insert Figure 3 About Here

For example, a student might have written the following statement to explain the connection:

The results of meiosis are sperm and egg cells which contain chromosomes and are used in Punnett squares to show how genes may combine to produce certain traits in offspring.

This student would receive a score of 3 for meiosis and a score of 4 for their statement of Punnett squares. These scores would be added to result in an overall meaningful relationship score of 7.

Students' scores on the conceptual relation ranged from 1 (rote) to a score of 10 (meaningful) and represent students' "relationship statements" between meiosis and Punnett squares (see Figure 3). These scores were used in the data analyses.

Results

Assignment of students to the two treatments

Of the 94 students assigned a meaningful learning orientation score, 53 had the reception form of instruction (told relationships between meiosis and Punnett squares) and 41 had the generative form of instruction (constructed relationships themselves). The frequency distribution of students with a meaningful

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score, a mid-range score and a rote score receiving either of the two treatments is shown in Table 1.

Insert Table 1 About Here

Statistical Analyses

The distinction of meaningful learning orientation from students' aptitude and achievement motivation. The first aim of this research was to determine whether meaningful learning orientation uniquely predicted students' attainment of meaningful understanding independent of aptitude and achievement motivation. Stepwise multiple regressions were conducted in which the variables of aptitude (DAT scores) and achievement motivation (questionnaire scores) were forced into the equation first, and students' meaningful learning orientation scores (n = 94) were entered last. The procedures were conducted to predict post-test mental model scores of meiosis, Punnett squares, and post-test mental model scores of the relation between meiosis and Punnett squares. The same procedure was also conducted on scores of students' relationship statements. The results of the stepwise multiple regressions in these analyses are shown in Table 2. Inter-correlations of the independent variables, and correlations of independent variables with dependent variables are shown in Tables 3 and 4.

Insert Tables 2, 3 and 4 About Here

In two of the four prediction equations (meiosis and Punnett squares), meaningful learning orientation uniquely explained the variance in post-test scores independent of that explained by aptitude and achievement motivation ($p < .01$). In a third prediction equation (meiosis and Punnett square method combination), meaningful learning orientation was significantly correlated with the dependent variable ($p < .01$), and was a significant predictor of this post-test. Although meaningful learning orientation did not predict students' relationship statements, it was concluded that meaningful learning orientation is a factor worthy of further investigation as to its possible contribution in predicting meaningful understandings of students. In general, it seems that meaningful learning orientation may be a unique predictor of meaningful understanding which was

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not fully explained by aptitude and motivation to achieve high grades, at least for mental models of meiosis, Punnett squares and the combination of meiosis and Punnett squares.

Consistency of students' meaningful understandings. The following analyses tested the proposition that students' attainment of understanding may be consistently rote, or consistently meaningful, or consistently mid-range between meaningful and rote for meiosis, Punnett squares and for measures of the combination and relationship between these two topics. Inter-correlations among the four post-test scores are shown in Table 5.

Insert Table 5 About Here

The results show that all post-test scores were significantly correlated with each other. The particularly high correlation between the mental model scores of the combination of meiosis and Punnett squares, and scores of students' relationship statement scores may be partly due to the fact that both scores were based on the same written explanations. In general, students were found to be consistent in the level of meaningful understanding they attained on the different topics and on the combination and relationship between the topics.

The influence of meaningful learning orientation, prior knowledge, and treatment on the attainment of meaningful understanding. Stepwise multiple regressions were conducted on post-test scores using meaningful learning orientation, prior knowledge and treatment as predictor variables (correlations are shown in Table 4). The results of the stepwise regressions for meiosis, the Punnett square method and the procedural combination and conceptual relation between these topics are summarized in Table 6.

Insert Table 6 About Here

As shown in Table 6, results of the regression analysis indicated that meaningful learning orientation and prior knowledge of meiosis are significant predictors of students' meaningful understanding of meiosis, the Punnett square method and the process-procedural combination between the topics. Students' meaningful

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learning orientation alone predicted their meaningful understanding of the conceptual relations represented in their relationship statements.

The influence of all possible interactions between meaningful learning orientation, prior knowledge, treatment on the attainment of meaningful understanding. Stepwise multiple regressions were conducted to determine the influence of the interaction terms as predictors of the four post-test scores (correlations are shown in Table 4). Entered into each regression equation were the following independent variables: (1) meaningful learning orientation x prior knowledge, (2) meaningful learning orientation x treatment, (3) prior knowledge x treatment, and (4) meaningful learning orientation x prior knowledge x treatment.

Stepwise multiple regressions for post-test mental model scores of meiosis revealed that only the interaction of prior knowledge of meiosis with meaningful learning orientation was a significant predictor $F(1,92) = 17.62$, $p = .0001$. The proportion of variance explained by the prior knowledge-meaningful learning orientation interaction variable was .16. The interaction of meaningful learning orientation with prior knowledge has been represented by a plot of three regression lines of post-test mental model scores of meiosis (y-axis) by prior knowledge (x-axis), for meaningful, mid-range and rote learners, shown in Figure 4.

Insert Figure 4 About Here

The regression lines shown in Figure 4 revealed a general increase in meiosis post-test scores as prior knowledge of meiosis increased for all three learner groups (meaningful, mid-range, rote). The interaction may be explained by the convergence of regression lines of rote, mid-range and meaningful learners with an increase in prior knowledge. Meaningful learning orientation accounts for smaller differences in post-test scores when prior knowledge is greater. It appears that when students have higher levels of prior knowledge, their meaningful orientation makes less of a difference in their meaningful understanding.

For students' mental models scores of Punnett squares, both the interaction of prior knowledge with meaningful learning orientation, and the interaction of treatment with meaningful learning orientation were significant. The proportion of variance explained by prior knowledge-meaningful learning orientation interaction

variable was .18, which was significant, $F(1,92) = 19.95$, $p = .0001$, and the proportion of variance explained by the treatment-meaningful learning orientation interaction variable was .04, $F(1,91) = 4.61$, $p = .0344$. The total proportion of variance in students' mental model scores of Punnett squares explained by both the prior knowledge-meaningful learning orientation interaction, and treatment-meaningful learning orientation interaction, was .22, $F(1,91) = 12.67$, $p = .0001$. The interaction of meaningful learning orientation with prior knowledge has been represented by a plot of regression lines of post-test mental model scores of Punnett squares by prior knowledge, for meaningful, mid-range, and rote learners, shown in Figure 5. The interaction of meaningful learning orientation and treatment is shown in Figure 6 with a graph of the regression lines of post-test mental model scores of Punnett squares by treatment for meaningful, mid-range and rote learners.

Insert Figures 5 and 6 About Here

The regressions lines shown in Figure 5 indicate that mental model post-test score of Punnett squares generally increased with prior knowledge for all three learner groups. However, the slope of the regression lines for meaningful and rote learners was greater than for mid-range learners. Mid-range learners' post-test scores for Punnett squares appeared to increase rather gradually with prior knowledge as compared with meaningful and rote learners, which could indicate the source of the interaction. Apparently, prior knowledge of meiosis had less of an effect on meaningful understanding of Punnett squares for mid-range learners than it did for either rote or meaningful learners. When comparing mid-range and rote learners, mid-range learners developed greater understanding than rote learners when they had little prior knowledge; but at higher levels of prior knowledge, meaningful learning orientation did not seem to make a difference in the understandings attained.

The regression lines for post-test scores of Punnett squares by treatment (Figure 6) for meaningful and rote learners were nearly parallel with the x-axis indicating that test scores essentially were not increased with the reception treatment as compared with the generative treatment. The slope for mid-range learners, however, increased relative to the reception treatment. This finding indicates that for mid-range learners, post-test scores of Punnett squares (a topic first introduced to students in the instructional packets) were increased

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when students were told relationships as compared to when they were asked to construct relationships themselves. The increase in post-test scores as a function of treatment for mid-range learners compared with the lack of increase for meaningful and rote learners, could be the source of the interaction.

For students' mental model scores of the meiosis and Punnett square method process-procedural combination, the interaction between prior knowledge and meaningful learning orientation was the best predictor $F(1,92) = 12.16$, $p = .0007$. The interaction term explained .12 of the variance in post-test mental model scores of the combination of meiosis and Punnett squares. The interaction of meaningful learning orientation with prior knowledge has been represented by a plot of the regression lines of post-test mental model scores of the combination of meiosis and Punnett squares by prior knowledge for meaningful, mid-range and rote learners, shown in Figure 7.

Insert Figure 7 About Here

The regression lines for meaningful, mid-range, and rote learners (Figure 7) generally indicated that mental model scores of the meiosis and Punnett square method combination increased as prior knowledge increased. The regression line for mid-range learners increased rather sharply with increased prior knowledge, as compared with the regression lines for meaningful and rote learners. The sharp increase in scores of this test with increased prior knowledge for mid-range learners, relative to scores for meaningful and rote learners, could be the source of the interaction. Mid-range learners with low prior knowledge of meiosis appeared to have formulated relatively comparable understandings of the process-procedural combination of meiosis and Punnett squares as did rote learners with low prior knowledge. However, mid-range learners seemed to have formulated a more meaningful understanding of the combination of meiosis and the Punnett square method when they had high prior knowledge, as compared with both meaningful and rote learners with high prior knowledge.

Finally, for the scores obtained from students' relationship statements which directly and conceptually linked meiosis and Punnett squares, again the interaction between students' meaningful learning orientation and prior knowledge was a significant predictor, explaining .05 of the variance, $F(1,92) = 5.32$, $p = .0234$. The

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regression equations for scores on relationship statements for meaningful, mid-range and rote learners were calculated and regression the regression lines have been presented in Figure 8.

Insert Figure 8 About Here

The regression lines shown in Figure 8 indicate that with low prior knowledge, meaningful learners apparently attained more meaningful understandings of the conceptual relations between the two topics than mid-range or rote learners. With high prior knowledge however, mid-range learners attained especially more meaningful understandings of the conceptual relations between the topics as compared with meaningful or rote learners.

The results of the regression analyses suggest that meaningful learning orientation and prior knowledge interacted when students explained topics separately from one another as in their mental models of meiosis and the Punnett square method, as well as when they described the procedural and conceptual relations between the topics. The interaction of meaningful learning orientation and treatment appears to have implications only in students' explanations of a newly learned topic (Punnett squares).

Discussion

This study explored the possible influence of students' meaningful learning orientation on their attainment of meaningful understanding of meiosis, Punnett squares, and the combination and relation between these topics. The findings indicated that meaningful learning orientation explained a unique portion of the variance from that explained by aptitude and achievement motivation in two of the four regression analyses (meiosis and Punnett squares). In addition, meaningful learning orientation correlated most highly with students' mental model scores of the relation between the topics and alone predicted these post-test scores. Students' tendency to approach learning by memorizing information or by making sense of information appeared to have a unique role in explaining the extent of their meaningful understanding.

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The influence of meaningful learning orientation on students' relationship statements, however, is less clear. In these statements, students linked certain meiosis concepts (such as, genes with chromosomes, genes and chromosomes with gametes), and *Punnett square concepts (such as,* gametes combine to show fertilization in Punnett squares). The research of Cho, Kahle and Nordland (1985) indicated that an understanding of connections between such concepts (i.e., genes and chromosomes) represents meaningful understanding since students know the hierarchical linkages. In this study, although students' meaningful learning orientation was correlated with connecting appropriate terms in their relationship statements, it was best explained by both aptitude and achievement motivation. Perhaps using the proper terms to cite the specific relations between the topics is difficult for students, even for those who actively attempt to formulate conceptual relations, and thus requires mainly high aptitude and a high achievement motivation.

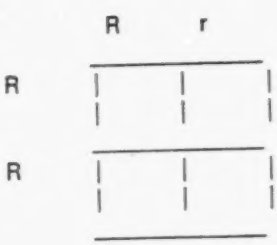
Another significant finding of this study was that the level of understanding that students attained for one topic was linearly and positively correlated with the level of understanding attained for the other topics. The indication that students attained similar levels (meaningful, rote) of understanding of the different biological topics has been supported in a research review by Novak (1988). According to Novak (1988), students in studies at Cornell reportedly spent 12 to 13 years in school learning by rote. The problem with consistent rote learning is that it is thought to "interfere with later similar learning" and make continued study inefficient (Novak, 1988, p. 85). Although Novak's (1988) claim was a generalization, it may be what has been evidenced in this study at least for the topics of meiosis, the Punnett square method, and their relationships.

Clearly, some major aspects of meiosis are important for attaining a conceptually meaningful understanding Punnett squares and are important for understanding the relationship. The following hypothetical example of questions and answers illustrates the importance of an understanding of meiosis:

Q: What is this?------>

A: A gene.

Q: Where does it come from?



A: A gamete.

Q: What is a gamete?

A: A sperm or egg cell.

Q: Where do sperm and egg cells come from?

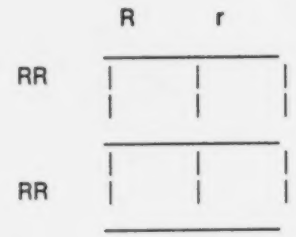
A: Male and female gonads.

Q: How?

A: Meiosis occurs (in spermatogenesis or oogenesis).

Q: Why didn't you write?---->

A: Because only one gene from a homologous pair of chromosomes are used in Punnett squares.



Q: Why?

If students do not know the answers to these questions they are missing some very important elements for meaningfully understanding the concepts that Punnett squares represent. Students may be able to properly use the Punnett square method to solve problems, as it is frequently reported (Cho, Kahle & Nordland, 1985; Stewart, 1982; Stewart & Dale, 1989; Tolman, 1982). However, without at least some of the conceptual linkages represented in the above example, the use of the Punnett square method may indeed be algorithmic (Stewart & Dale, 1989).

Other findings of this study support the importance of both meaningful prior understanding of meiosis and also of having a meaningful learning orientation in attaining meaningful understandings of new information. The results of the stepwise multiple regression analyses generally indicated that prior knowledge and meaningful learning orientation predicted students' meaningful understanding of meiosis and Punnett squares, and the process-procedure combination of these topics. The interaction of prior knowledge and meaningful learning orientation also predicted meaningful understanding of each topic.

For meiosis, with high prior knowledge the differences between all three learner groups' understanding of meiosis were less than they were with low prior knowledge. Meaningful learners with high prior knowledge

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did not acquire much greater understanding of meiosis than did mid-range learners with high prior knowledge. In general, however, students who were meaningful learners attained greater meaningful understandings of meiosis than either mid-range or rote learners. This is evidenced by the positive correlations of meaningful learning orientation with meiosis post-test scores (Table 4), and was reinforced by the position of the regression lines in Figure 1. Additionally, all students with high prior knowledge of meiosis attained greater meaningful understanding than those with low prior knowledge of meiosis as indicated by correlations and the slopes of the regression lines.

The regression lines for the interaction of meaningful learning orientation and prior knowledge were aligned in a different pattern for Punnett squares (a newly learned topic) than they were for meiosis (a previously learned topic, reviewed in the instructional packets). The lines representing the interaction for Punnett squares (Figure 2) indicate that with low prior knowledge of meiosis, the understandings of meaningful and mid-range learners were not much different. However, with high prior knowledge of meiosis, the meaningful learners appeared to have greater understanding of Punnett squares than mid-range learners. In terms of rote and mid-range learners, with low prior knowledge, mid-range learners appeared to have manifested greater meaning than rote learners. But, with high prior knowledge the understandings of rote and mid-range learners were similar. Furthermore, the positions of the regression lines and significant positive correlations (Table 4) indicate that meaningful learners attained higher levels of meaningful understanding of Punnett squares than mid-range or rote learners. Correlation and regression results also indicate that as prior knowledge of meiosis was increased, meaningful understanding of Punnett squares generally increased, particularly for meaningful and rote learners. From the appearance of the regression lines, mid-range learners are not as likely as meaningful and rote learners to use their higher levels of prior knowledge to create meaningful understanding.

The regression lines (meaningful learning orientation x prior knowledge) for students' understanding of the process-procedure combination between meiosis and Punnett squares revealed that the likely source of the interaction was again the mid-range learner group. With low prior knowledge, mid-range learners had approximately the same level of understanding as rote learners. With high prior knowledge, however, mid-range learners had more meaningful understandings of the relation than rote learners. Also apparent was that

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mid-range learners and meaningful learners had similar understandings with high prior knowledge. But, with low prior knowledge, meaningful learners had greater understandings than mid-range learners.

Positive correlations indicate that students with a meaningful learning orientation generally attained more meaningful understandings of the combination than those with mid-range and rote learner orientations. It is also evident that all three learner groups attained more meaningful understandings of the combinations between the topics with high prior knowledge than with low prior knowledge. Visual inspection of the regression lines reveals that, compared with meaningful and rote learners, mid-range learners' meaningful understanding was increased rather markedly as prior knowledge increased. Possibly, greater prior knowledge of meiosis helped mid-range students better understand how the process of meiosis and the Punnett square procedure are combined. This proposition is supported by Entwistle & Ramsden (1983), who contend that students may need to use both rote and meaningful learning approaches to attain complete understandings. This may explain the finding that mid-range learners (who may tend to use both rote and meaningful strategies to some extent) attained a more meaningful understanding of the combination of the topics than rote or meaningful learners.

The same conclusions may explain findings revealed by students' relationship statements. In the analyses of students' relationship statements, the interaction of meaningful learning orientation and prior knowledge was again a significant predictor of students' understanding. Once again, the mid-range learners appeared to attain higher meaningful understandings of the conceptual relations with high prior knowledge as compared to meaningful or rote learners. It seems that with a meaningful understanding of meiosis, mid-range learners may be able to meaningfully understand how meiosis and the Punnett square method are conceptually related. Comparing results of mid-range learners on the Punnett square mental model test with both the process-procedure combination and relationship statements may offer some insight as to how these students learn. It is speculated that when mid-range learners are told to relate meiosis with the Punnett square method as in the mental model question asking students to explain the relationship between the topics, they may use their prior knowledge of meiosis. When they are not specifically told to make a relationship between meiosis and Punnett squares, as in the mental model question asking them to explain only the Punnett square method, they may not use prior knowledge of meiosis to help in their explanations. In essence, if mid-range learners

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have high prior knowledge and are *told* to relate new topics with this prior knowledge they may show a more inter-related, meaningful understanding of topics. This speculation may be reinforced by the finding that mid-range learners performed better than rote learners on the Punnett square test when they were *told* relationships (reception treatment), but performed about the same as rote learners when *not told* the relationships between the topics (generative treatment). If the relationships between meiosis and Punnett squares are explained for mid-range learners, the information may help them recognize how the topics are connected, and allow them to formulate a more meaningful understanding of Punnett squares.

These findings seem to be in contrast with those of Wittrock and Alesandrini (1990), who found that students' generation of summaries that specifically related conceptual information they read in text resulted in increased learning as compared with just reading the information. In this study, the opposite result occurred for mid-range learners. Perhaps if students had been *forced* to answer the relational questions presented in text, the results would have been more aligned with those of Wittrock and Alesandrini (1990). The intention of allowing students to answer questions if they desired (rather than force them to answer) was done to avoid interference with their particular learning approach. A similar technique was used in a study by Marton (1976, in Entwistle & Ramsden, 1983), who left instructions for reading an article vague so that students could decide for themselves whether "reading for understanding or rote memorization would be the best way of answering the subsequent questions about the article" (p. 22). Allowing students to "decide for themselves" how to approach learning was also the intention of this study. Perhaps if students with the generative treatment were forced to answer the relationship questions as in a study by Pask and Scott (1972, in Entwistle & Ramsden, 1983), there might have been more of a treatment effect. Of course, simply because answers were provided for students in the reception treatment did not mean that all students read or made sense of those answers. More research is needed to clarify the effect of treatment on meaningful understanding.

The persistent finding that prior knowledge of meiosis was positively correlated with students' meaningful understandings supports research conducted by Stewart and Dale (1989). Their research reported that prior knowledge of meiosis was critical for meaningfully understanding the Punnett square method in genetics and for understanding the relationship between meiosis and the use of Punnett squares to solve genetics problems (Stewart & Dale, 1989). Results of this study extended those of Stewart and Dale's (1989)

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research with the finding that not only prior knowledge of meiosis was important, but how this prior knowledge is used by learners. If students have the requisite knowledge of meiosis and they have a tendency to actively integrate what they know with new information, they were likely to have achieved a meaningful understanding of the material. It is not known whether students' prior knowledge activated the meaningful learning set or whether the tendency to meaningfully learn activated their prior knowledge while they were first learning the information. What was indicated, however, was that students who tended to learn meaningfully and who had meaningful prior knowledge of meiosis were likely to have attained a meaningful understanding of the material. Thus, the meaningful understanding attained was generally a factor of both how students tend to learn (meaningful, mid-range, rote) and the level of requisite knowledge they had of meiosis.

In summary, it is evident across the analyses that the variable which was prevalent in each prediction equation was meaningful learning orientation. Meaningful learning orientation interacted with prior knowledge in predicting students' mental models of meiosis, Punnett squares and the combination of meiosis and Punnett squares. Meaningful learning orientation also interacted with treatment to predict students' meaningful understanding of Punnett squares. Meaningful learning orientation alone significantly predicted meaningful understanding of students' relationship statements. The findings pertaining to meaningful learning orientation in this study extend the work of other researchers (Atkin, 1977; Donn, 1989; Edmonson, 1989; Entwistle & Ramsden, 1983; Robertson, 1984) who identified and described how students approach learning (meaningful, rote). The present study not only identified and described students' approach to learning, but also discovered an important relation between the students' learning approach and their attainment of meaningful understanding.

Educational Implications

Educators have expressed concern that a large number of high school students learn primarily by rote (Novak, 1988; Ridley & Novak, 1983; Tobin & Fraser, 1989). One important aspect of this study was that it attempted to characterize what is meant by meaningful and rote learning, and subsequently identify how individual students tended to approach learning. Much work has to be done to improve the capacity of

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identifying students' learning orientations, and the use of a combination of self-reports and teacher observations should be further researched.

This study revealed several potential benefits to knowing how students learn. Students' meaningful learning orientation played a part in the prediction of students' attainment of meaningful understanding. There was a direct relation between meaningful learning orientation and students understandings: the more meaningful the students' learning orientation, the more meaningful the understandings they tended to attain. By knowing how students approach learning, students that do not tend to learn meaningfully can perhaps be "taught" to do so (see Novak & Gowin, 1984), which in turn, may help them formulate more meaningful understandings of the information presented to them in teaching. Additionally, students who tend to meaningfully learn should be encouraged to continue their efforts toward making sense of new information in order that they may continue to attain meaningful understandings of that information.

A major finding of this research was that prior knowledge is important for meaningful understanding. This study revealed that educators should continue to concentrate on helping students develop a framework of knowledge in an area. But, educators should also concentrate on helping students activate and use this knowledge in the formulation of meaningful understanding. Some educators may believe that their major role is to provide "content" to students. But this content may be learned as arbitrary facts and exist in isolation from other concepts in the learners' mind. Perhaps if students are also taught (and learn) to continuously relate this content with what they may already know, and to actively formulate relationships between concepts within the content they are learning, a more meaningful understanding of science would be attained.

FIGURES AND TABLES

Figure 1. Student distribution into four categories based on a division of LAQ scores.

LAQ score	category	number of students
Highest one-fourth (more meaningful)	4	34
2nd highest one-fourth	3	38
3rd highest one-fourth	2	39
Lowest one-fourth (more rote)	1	29

Figure 2. Matrix used to plot macro-structure and micro-structure scores of meiosis. The frequency distribution of scores for the meiosis post-test mental model is shown in the cells of the matrix.

MEIOSIS

CONCEPTUAL SCORE

PROCESS SCORE	1	2	3	4	5	6
1	6	1	5	-	-	-
2	1	11	16	4	26	10
3	-	1	7	1	5	3
4	-	-	1	-	4	2
5	-	-	-	-	13	3
6	-	-	-	-	3	4

Quadrant I | Quadrant II | Quadrant III | Quadrant IV

	Mental model	Score	Frequency
Not Represented:	no understanding	0	13
Quadrant I:	rote understanding	1	48
Quadrants II & III:	intermediate	2	50
Quadrant IV:	meaningful understanding	3	29
			N = 140

Figure 2 (con't). Matrix used to plot conceptual and procedural scores of Punnett squares. The frequency distribution of scores for the Punnett square post-test mental model is shown in the cells of the matrix.

PUNNETT SQUARES

CONCEPTUAL SCORE

PROCEDURAL SCORE	1	2	3	4	5
1	2	-	1	-	-
2	6	34	4	-	-
3	2	11	10	3	1
4	1	13	8	3	-
5	-	4	2	1	2

Quadrant I | Quadrant II | Quadrant III | Quadrant IV

	Mental model	Score	Frequency
Not Represented:	no understanding	0	32
Quadrant I:	rote understanding	1	42
Quadrants II & III:	intermediate	2	36
Quadrant IV:	meaningful understanding	3	30
			N = 140

Figure 2 (con't). Matrix of distribution of students' mental model scores of the relationship between meiosis and Punnett squares. Students' process scores of meiosis and procedural scores of the Punnett square are the values written on the outside of the matrix. Student frequencies are written within the cells.

PUNNETT SQUARES PROCEDURAL SCORE

MEIOSIS PROCESS SCORE	1	2	3	4
1	15	27	3	1
2	12	17	5	2
3	0	3	1	0
4	1	1	3	3

Quadrant I | Quadrant II | Quadrant III | Quadrant IV

	Mental model	Score	Frequency
Not Represented:	no understanding	0	32
Quadrant I:	rote understanding	1	42
Quadrants II & III:	intermediate	2	36
Quadrant IV:	meaningful understanding	3	30
			N = 140

Figure 3. Scoring procedure for students' relationship statements (conceptual relations) between meiosis and the Punnett square method.

KEY: MEANINGFUL UNDERSTANDING SCORE = COLUMN A SCORE + COLUMN B SCORE

COLUMN A		COLUMN B	
Score	Meiosis	Score	Punnett squares
1 =	Results of meiosis are...	1 =	...used in Punnett squares
2 =	Results of meiosis are sperm and egg cells (or gametes) which are...	2 =	...used in Punnett squares to show how genes may combine
3 =	Results of meiosis are sperm and egg cells (or gametes) which contain chromosomes which are...	3 =	...used in Punnett squares to show how genes may combine to produce traits (or characteristics).
4 =	Results of meiosis are sperm and egg cells (or gametes) which contain chromosomes which are...	4 =	...used in Punnett squares to show how genes may combine to produce certain traits in offspring.
5 =	Results of meiosis are sperm and egg cells (or gametes) which contain chromosomes with genes for certain traits, which are...	5 =	...used in Punnett squares to show how genes from sperm and egg cells (or gametes) may combine to produce certain traits in a fertilized egg cell (or zygote).

Interpretation of overall meaningful understanding score
(Score = Column A score + Column B score):

0 1 2 3 4 5 6 7 8 9 10

No understanding of relationship — Rote — Meaningful

Figure 4. Regression lines for post-test scores of meiosis by prior knowledge for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and prior knowledge in predicting means of post-test mental model scores of meiosis.

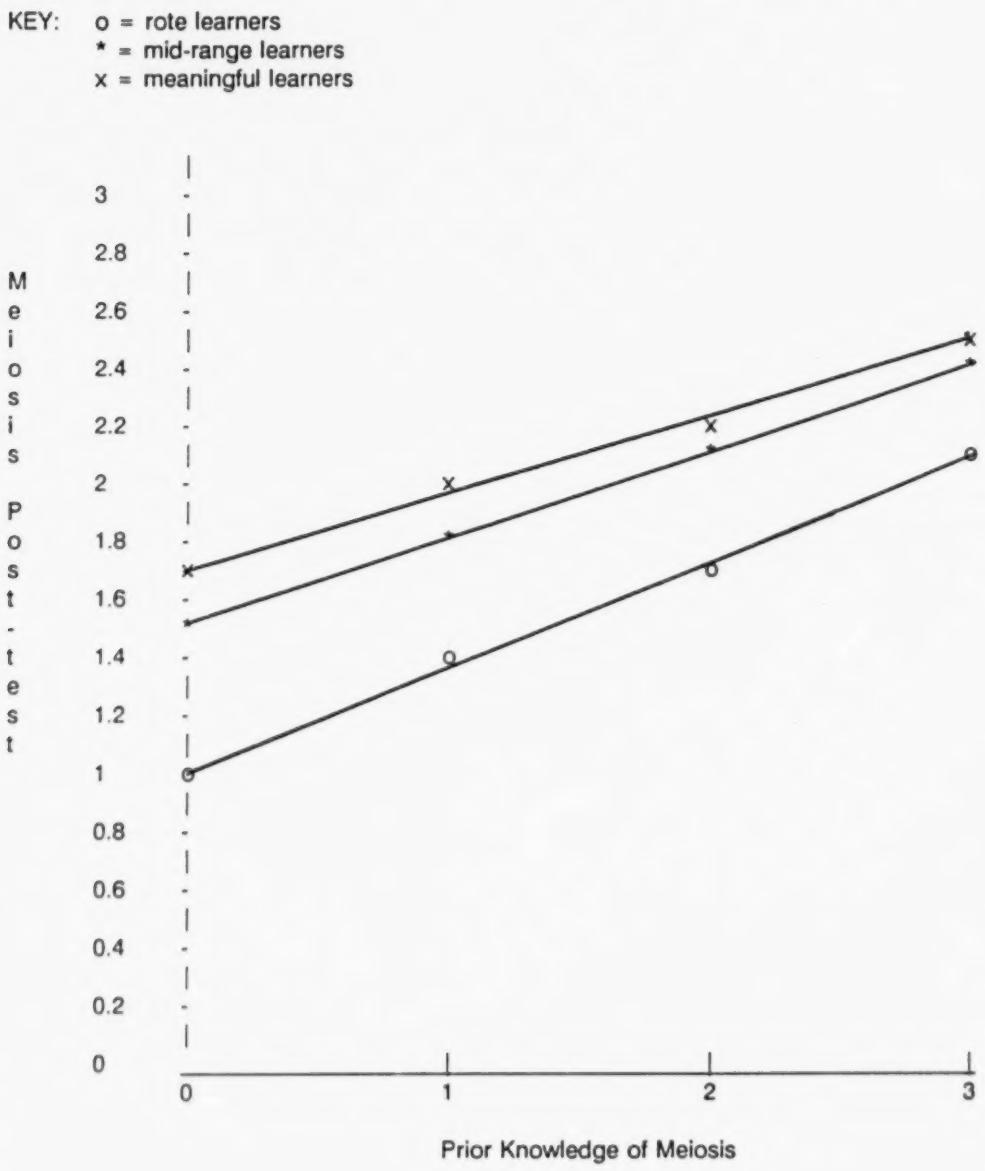

Figure 5. Regression lines for post-test scores of Punnett squares by prior knowledge for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and prior knowledge in predicting means of post-test mental model scores of Punnett squares.

KEY: o = rote learners
* = mid-range learners
x = meaningful learners

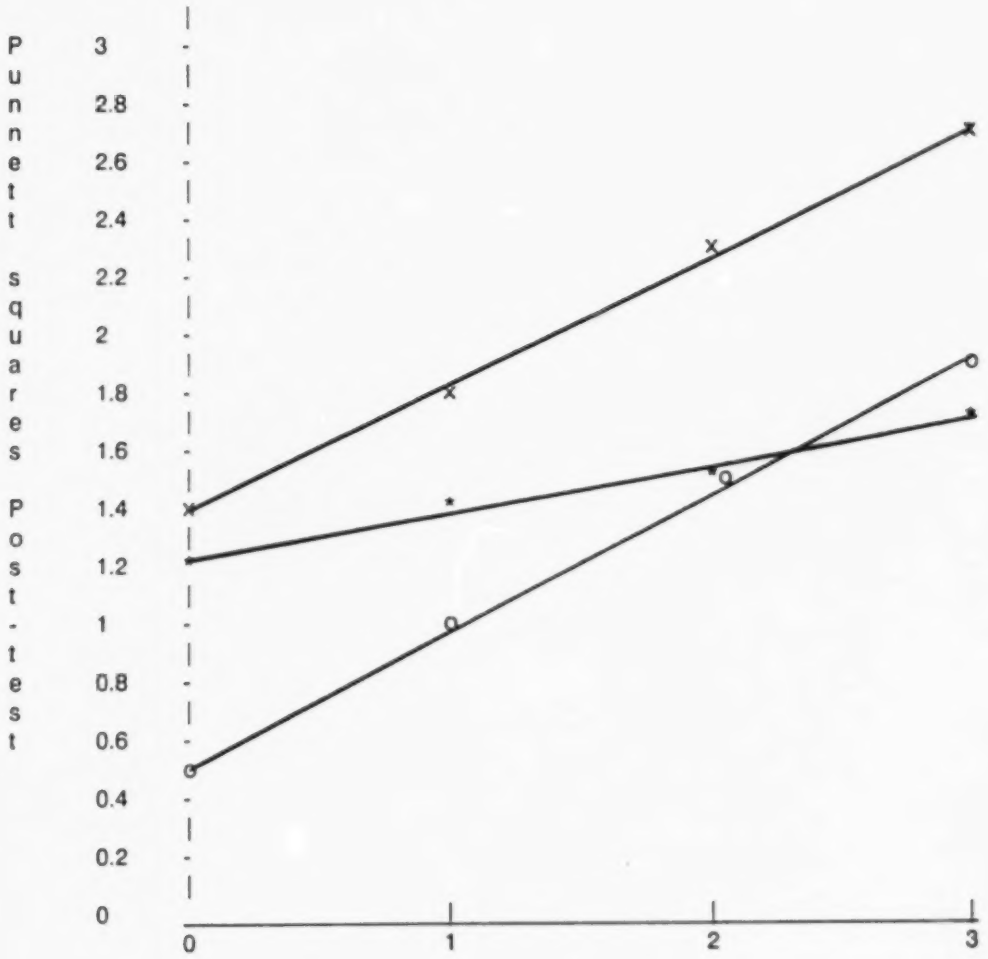

Figure 6. Regression lines for post-test scores of Punnett squares by treatment for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and treatment in predicting means of post-test mental model scores of Punnett squares.

KEY: o = rote learners
* = mid-range learners
x = meaningful learners

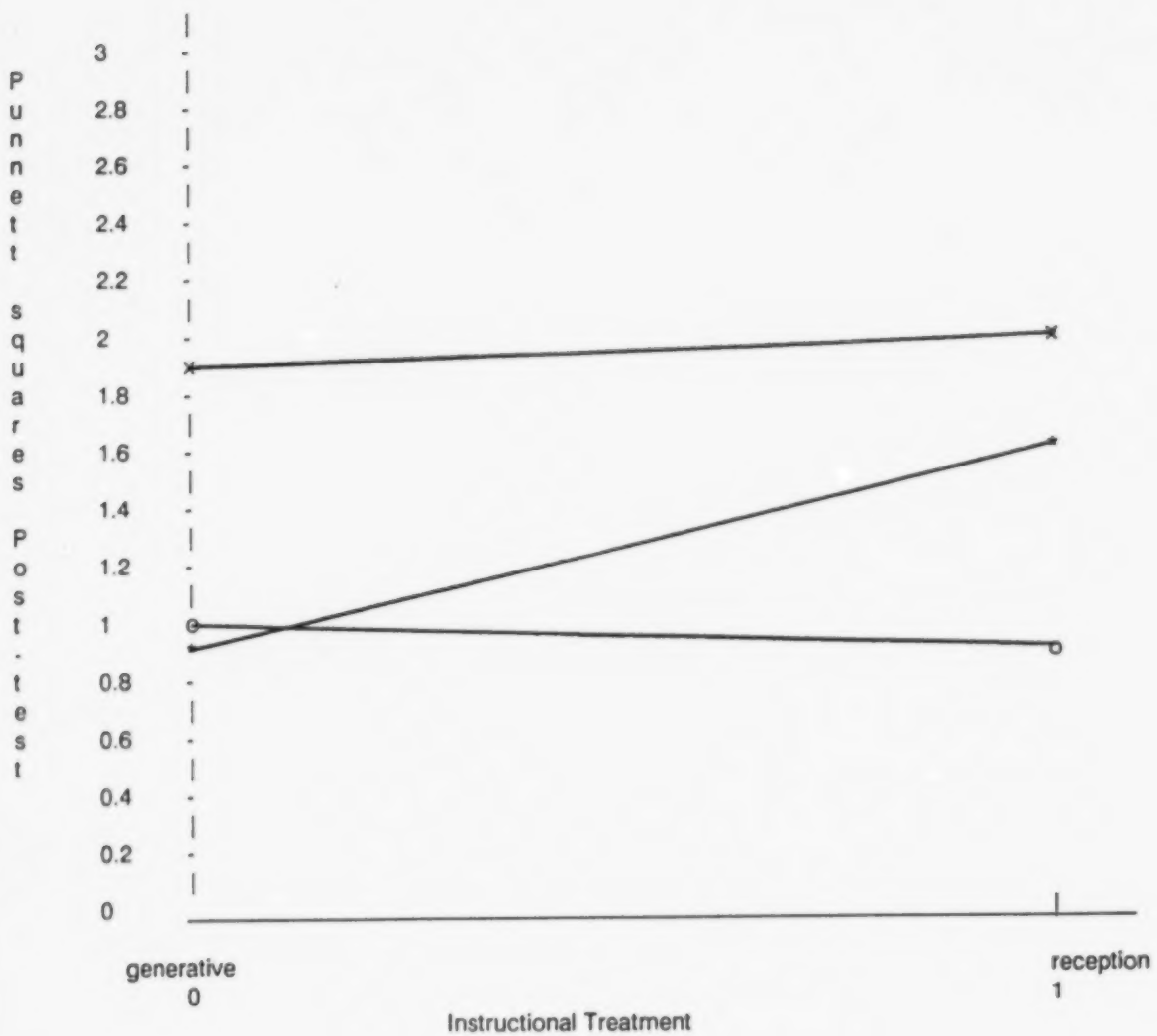

Figure 7. Regression lines for post-test mental model scores of the process-procedural combination of meiosis and Punnett squares by prior knowledge for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and prior knowledge in predicting means of post-test mental model scores of the process-procedural combination of the topics.

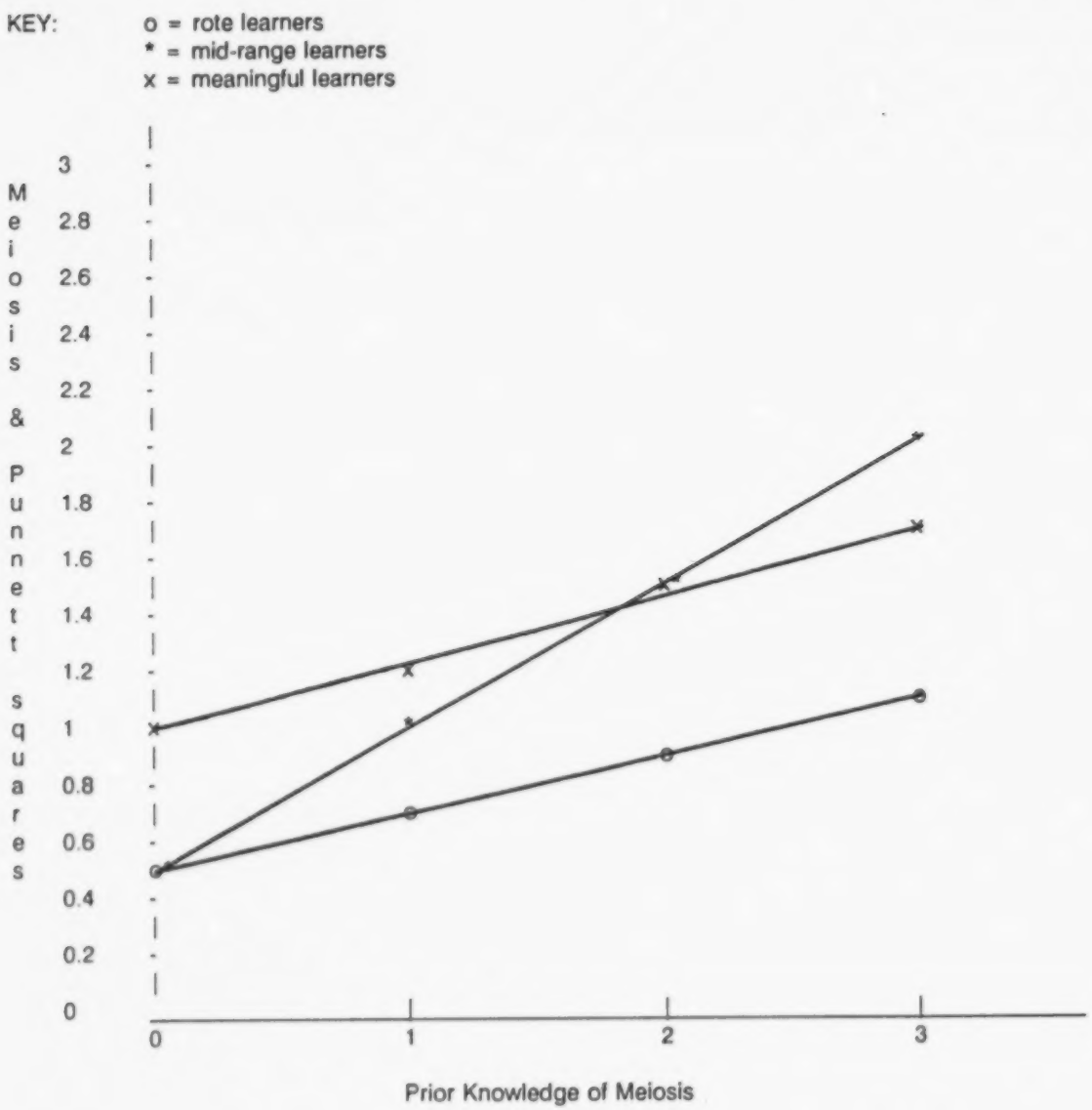

Figure 8. Regression lines for post-test scores of students' relationship statements by prior knowledge, for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and prior knowledge in predicting means of post-test mental model scores of the conceptual relation.

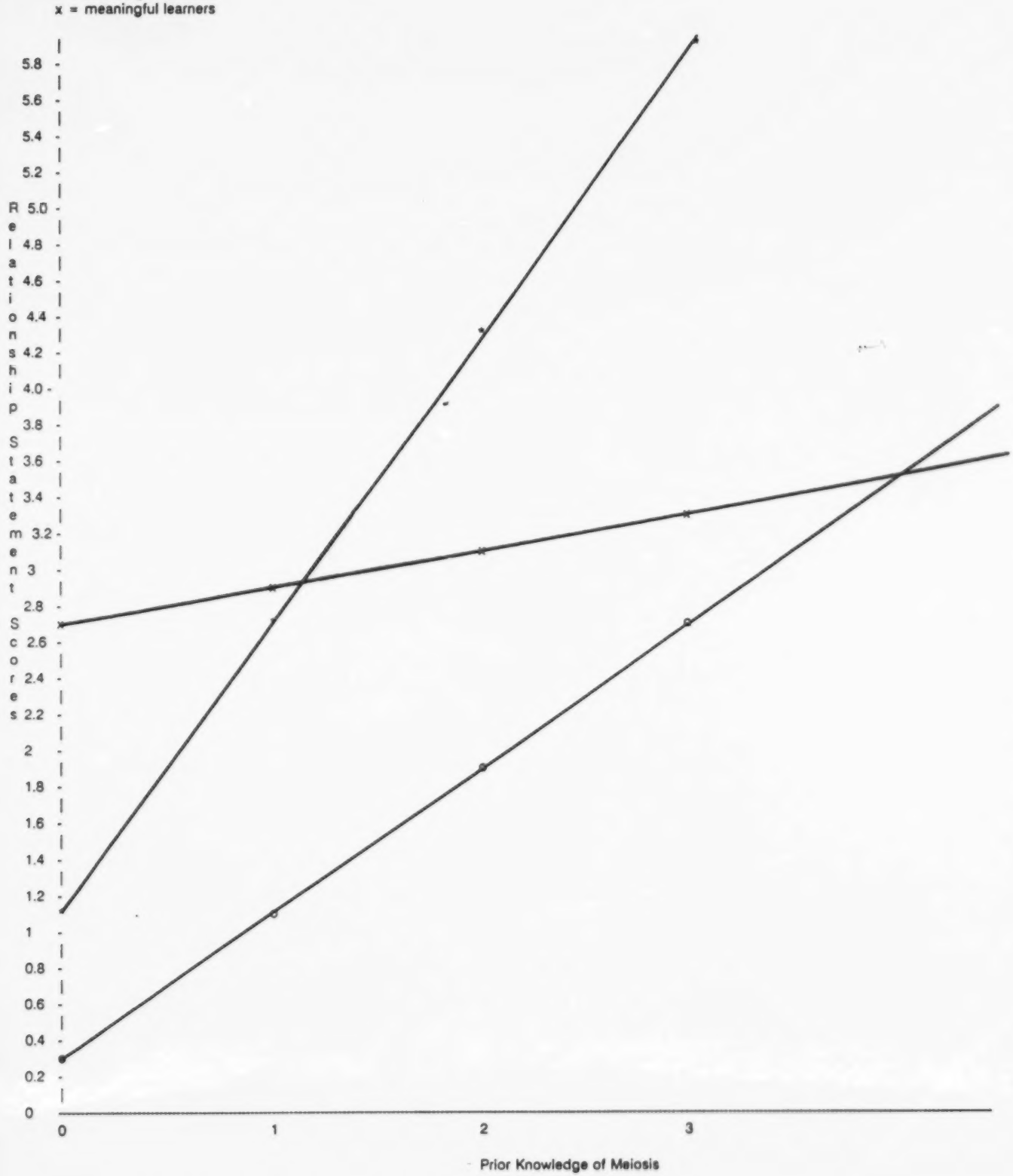

Table 1. Frequency distribution of students' meaningful learning orientation score by treatment (receive relationships, construct relationships).

	Reception Treatment	Generative Treatment	Totals
Rote Learning Orientation	18	16	34
Mid-range Learning Orientation	14	8	22
Meaningful Learning Orientation	21	17	38
Totals	53	41	94

Table 2. Contribution of meaningful learning orientation to the prediction of post-test scores with aptitude and achievement motivation forced into each regression equation first.

Post-tests		Forced variables: aptitude + achievement motivation	Forced variables: meaningful learning orientation	Total model
Meiosis	R^2	.094	.074	.168
	F	4.58	7.09	5.86
	p	.0128	.0067	.0012
Punnett squares	R^2	.116	.107	.223
	F	5.79	11.9	8.32
	p	.0043	.0009	.0001
Meiosis & Punnett squares combination	R^2	.021	.046	.067
	F	0.94	4.27	2.07
	p	.3940	.0418	.1081
Relationship statements	R^2	.116	.023	.139
	F	5.77	2.34	4.68
	p	.0044	.1300	.0046

Table 3. Inter-correlation matrix of the independent variables used in this study. DAT = Differential Aptitude Test, AM = Achievement motivation, MLO = Meaningful learning orientation, PK = prior knowledge of meiosis, TR = Treatment, MLO x PK = Meaningful learning orientation x prior knowledge interaction term, MLO x TR = Meaningful learning orientation x treatment interaction term, PK x TR = Prior knowledge x treatment interaction term, MLO x PK x TR = Meaningful learning orientation x prior knowledge x treatment interaction term.

	DAT	AM	MLO	PK	TR	MLO X PK	MLO X TR	PK X TR	MLO X PK X TR
DAT	-	.30**	.38**	.04	-.13	.14	.07	-.05	.05
AM		-	.15	.04	-.08	.06	.05	.01	.04
MLO			-	.15	.02	.49**	.41**	.14	.35**
PK				-	-.25*	.88**	-.14	.34**	.35**
TR					-	-.17	.85**	.59**	.50**
MLO X PK						-	.04	.35**	.46**
MLO X TR							-	.59**	.67**
PK X TR								-	.92**
MLO X PK X TR									-

*$p < .05$. **$p < .01$.

Table 4. Correlation table of the independent variables with the dependent variables used in this study. Independent variables: DAT = Differential Aptitude Test, AM = Achievement motivation, MLO = Meaningful learning orientation, PK = prior knowledge of meiosis, TR = Treatment, MLO x PK = Meaningful learning orientation x prior knowledge interaction term, MLO x TR = Meaningful learning orientation x treatment interaction term, PK x TR = Prior knowledge x treatment interaction term, MLO x PK x TR = Meaningful learning orientation x prior knowledge x treatment interaction term. Dependent variables: Post-test mental model scores of Meiosis, Punnett squares, the combination of meiosis and Punnett squares, and scores of students' relationship statements.

		Dependent Variables			
Independent Variables		Meiosis	Punnett squares	Meiosis & Punnett squares combination	Relationship statements
DAT	r	.29**	.26*	.13	.32**
AM	r	.02	.28**	.02	.05
MLO	r	.35**	.38**	.27**	.27**
PK	r	.34**	.34**	.29**	.19
TR	r	-.05	.07	-.12	-.16
MLO x PK	r	.40**	.42**	.34**	.23*
MLO X TR	r	.08	.21*	.01	-.02
PK X TR	r	.09	.23*	.005	-.0009
MLO X PK x TR	r	.17	.32**	.12	.11

*$p < .05$. **$p < .01$.

Table 5. Correlation matrix of the post-test mental model scores for meiosis, Punnett squares, the combination of meiosis and Punnett squares, and the relationship statement scores.

Variables	1	2	3	4
1. meiosis	-	.45**	.32**	.39**
2. Punnett squares		-	.42**	.38**
3. Meiosis & Punnett squares combination			-	.70**
4. Relationship statements				-

* $p < .05$, ** $p < .01$.

TABLE 6. Stepwise multiple regressions on students' meaningful understanding (post-test scores) of meiosis, the Punnett square method and the procedural combination and conceptual relation (relationship statements), with students' meaningful learning orientation, prior knowledge and treatment as predictor variables.

POST-TEST	PREDICTOR VARIABLES (SIGNIFICANT $p<.05$)	VARIANCE	F	p
MEIOSIS	MEANINGFUL LEARNING ORIENTATION	.12	12.97	.0005
	PRIOR KNOWLEDGE	.08	9.69	.0025
PUNNETT SQUARES	MEANINGFUL LEARNING ORIENTATION	.14	15.40	.0002
	PRIOR KNOWLEDGE	.08	9.67	.0025
PROCEDURAL COMBINATION	PRIOR KNOWLEDGE	.08	8.33	.0048
	MEANINGFUL LEARNING ORIENTATION	.05	5.62	.0198
RELATIONSHIP STATEMENTS	MEANINGFUL LEARNING ORIENTATION	.07	7.47	.0075

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